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Evaluation of Microphone Windscreen Performance in a Wind Tunnel

by Tung-Duong Tran-Luu and Latasha Solomon

ARL-MR-0636 December 2005

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ARL-MR-0636 **December 2005**

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REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 0704-0188*

1. REPORT DATE *(DD-MM-YYYY)*	**2. REPORT TYPE**	**3. DATES COVERED (From - To)**
December 2005	Interim	August 2005 to November 2005

4. TITLE AND SUBTITLE Evaluation of Microphone Windscreen Performance in a Wind Tunnel	**5a. CONTRACT NUMBER**
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S) Tung-Duong Tran-Luu and Latasha Solomon	**5d. PROJECT NUMBER** 5NE4TI
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) U.S. Army Research Laboratory ATTN: AMSRD-ARL-SE-SA 2800 Powder Mill Road Adelphi, MD 20783-1197	**8. PERFORMING ORGANIZATION REPORT NUMBER** ARL-MR-0636
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) U.S. Army Research Laboratory 2800 Powder Mill Road Adelphi, MD 20783-1197	**10. SPONSOR/MONITOR'S ACRONYM(S)**
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

Turbulent wind noise can severely degrade acoustic signals often making it difficult to detect, classify, and/or track signals of interest. Windscreens are often used to suppress such noise. This research compares the effectiveness of various windscreens to suppress wind noise while tested in a controlled environment.

15. SUBJECT TERMS

Acoustics, laminar wind flow, turbulent wind flow, signal processing, windscreen

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON** Latasha Solomon
a. REPORT Unclassified	**b. ABSTRACT** Unclassified	**c. THIS PAGE** Unclassified	UL	32	**19b. TELEPHONE NUMBER** (*Include area code*) 301-394-2180

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39.18

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Acknowledgments

We would like to thank NCPA at the University of Mississippi for graciously letting us use their wind tunnel. We would especially like to thank Jeremy Webster for assisting us with great dedication and ingenuity during the length of the experiment.

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Summary

Reduction of wind noise flow has been of interest to researchers in the acoustic signal processing arena for many years. It is desirable to obtain a medium that is resilient to extreme temperatures, dusts, and pests, such as insects and birds, while reducing wind noise. Five different windscreens were evaluated in a controlled environment as an initial test to compare their effectiveness at reducing wind noise.

Introduction

The objective of this research is to compare the performance of various windscreens in a controlled environment. Air flow, be it laminar or turbulent, produces pressure variation that can be detected by a microphone. It is a source of noise for most Army applications, where the intent is to listen to distant vehicles, gun fire, explosions, helicopters, etc. A microphone windscreen is a simple means to filter out such wind noise. An experiment comparing the performance of five different windscreens was conducted at the University of Mississippi, Oxford, MS, over a period of two days in August 2005.

Experimental Setup and Equipment

The following windscreens were tested during this experiment:

- 6” foam ball
- 3” foam ball
- Furry ball
- Horse hair
- Sara disk
- No windscreen

The wind speed was varied (0, 6, 9, and 12 m/s) for both laminar flow and turbulent flow.

A reference signal was played through a speaker placed near the tunnel intake for many combinations of wind speed, flow type, and windscreen. Some combinations were left out because of time constraint, impracticality, or loss of equipment (the 3 in. foam ball was sucked into the tunnel during one of the experiments). Our reference signal is a tonal sweep from 50 to 500 Hz, in step of 5 Hz. Each tone was programmed to be played for 100 cycles; however, our data did show some deviation. The same experiment would be repeated again with no reference signal, but only wind noise.

The acoustic signal acquired by the Knowles microphone (BL1994) is sampled with an Aerostat box at 1 kHz. The signal acquired with the B&K Type 4166 (200 V dc sensitivity) microphone is sampled at 5 kHz.

Figures 1 through 6 illustrate the experimental setup.

Figure 1. Wind tunnel intake and speaker used to generate sweep signal.

Figure 2. Setup for B&K microphone.

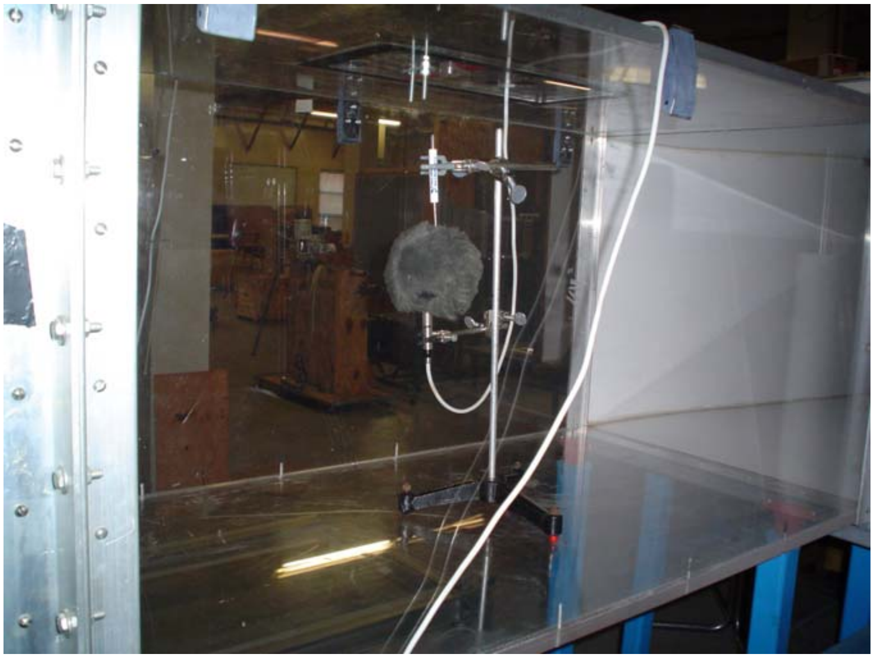

Figure 3. High wind speed generated excessive mechanical vibration on the furry windscreens as these were not designed to fit on the B&K microphone. So they were held in place by lightly sticking a screw driver into them.

Figure 4. Setup for the Knowles microphone and the Sara microphone. The Aerostat box recorded data in both cases.

Figure 5. Setup for horse hair windscreen and B&K microphone.

Figure 6. Grid (grey plastic tubes) used to create turbulent flow.

Experimental Results

We only show in figures 7 through 18 the data for the reference tones at frequencies of 50, 100, and 200 Hz. The behavior is qualitatively the same for the other 91 – 3 = 88 frequencies. For each reference tone, we normalize the power spectrum densities (PSD) of the signal at the frequency of the reference signal to 0 dB. The difference in power between the reference tone peaks and the noise floor indicates how well the windscreen is suppressing the wind noise. B&K results are not illustrated for 9 m/s turbulent wind flow because noise levels were too high to produce qualitative results.

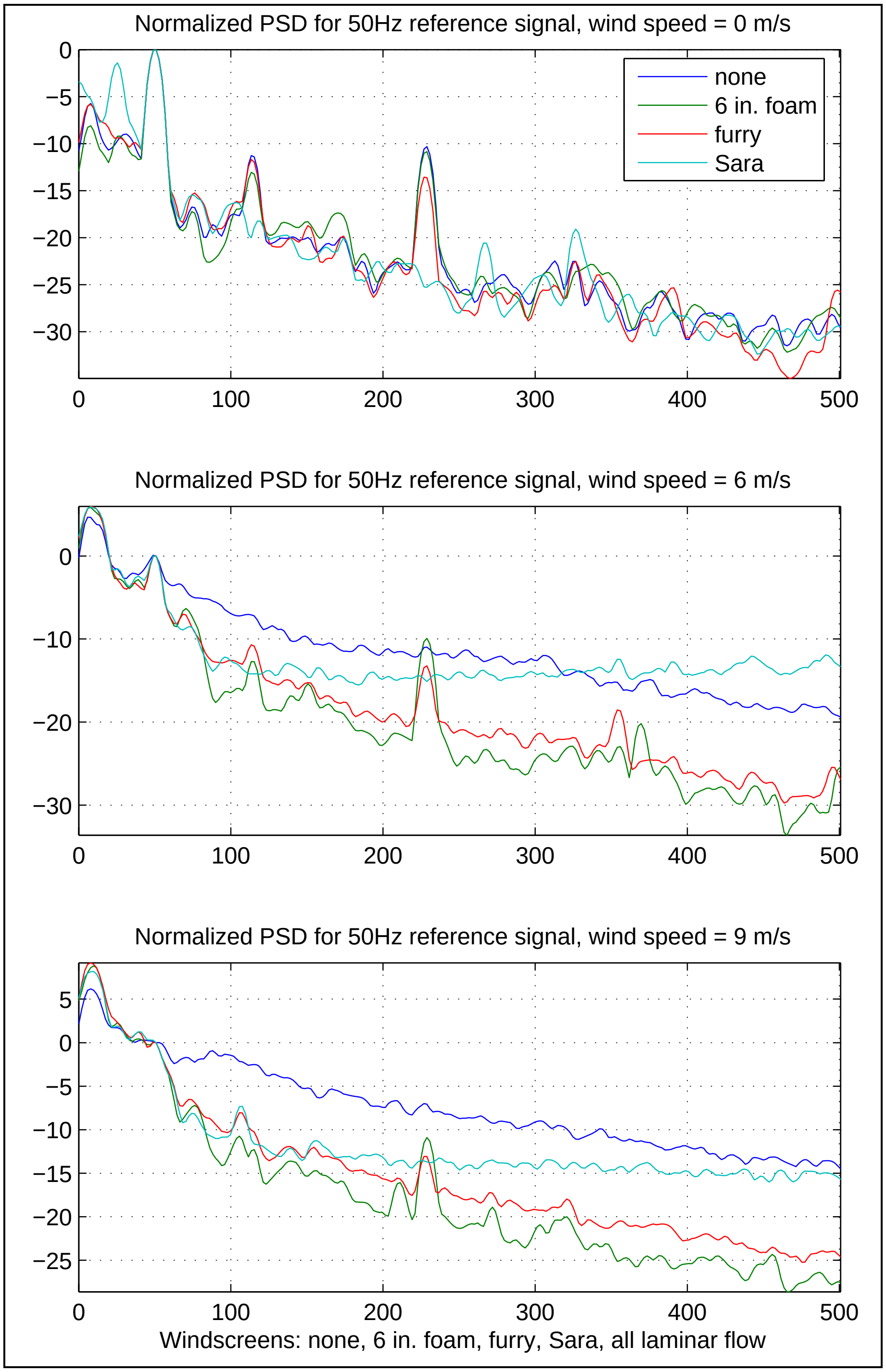

Figure 7. PSD normalized at 50 Hz, increasing laminar wind speed, Knowles microphone.

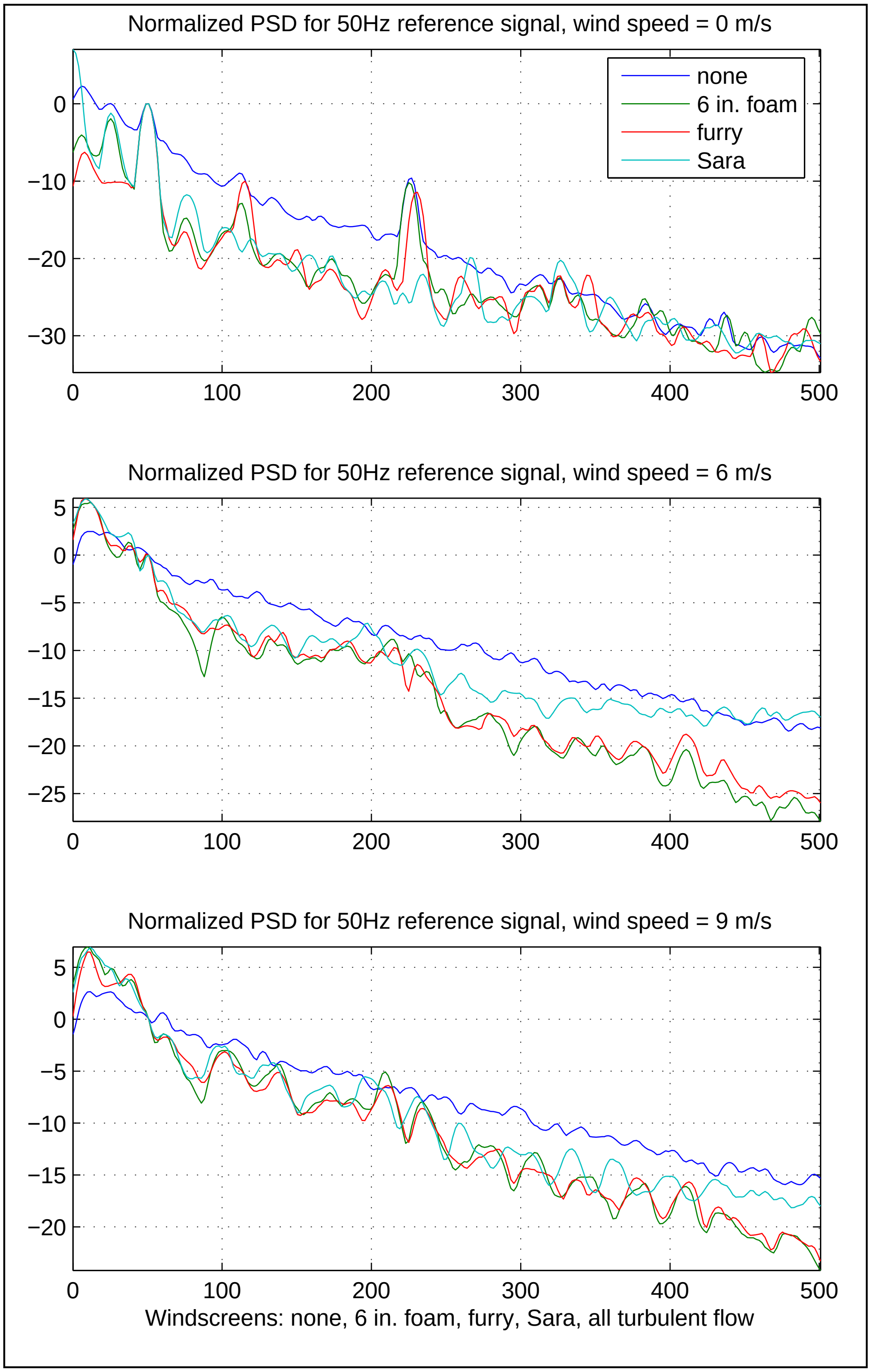

Figure 8. PSD normalized at 50 Hz, increasing turbulent wind speed, Knowles microphone.

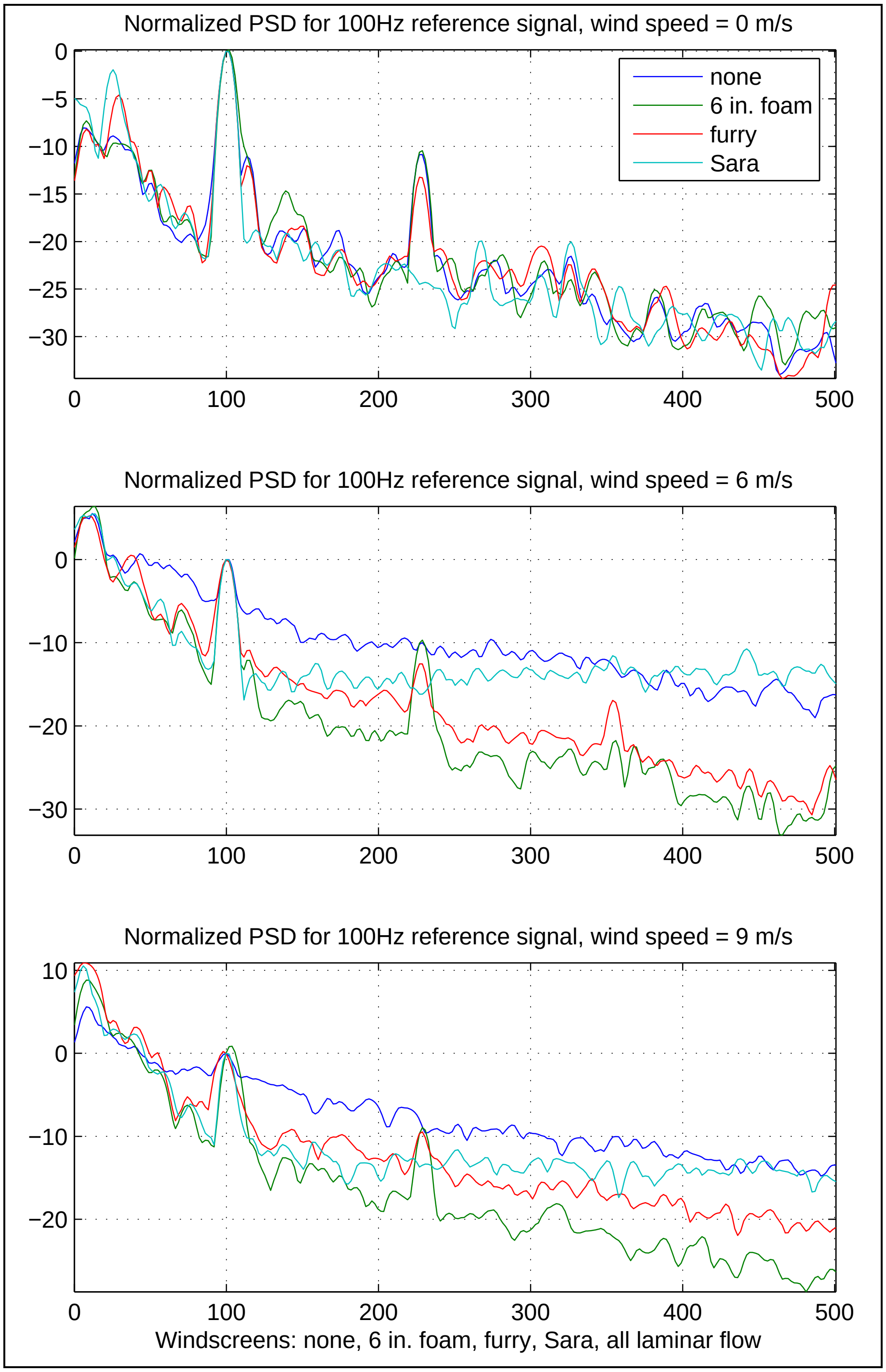

Figure 9. PSD normalized at 100 Hz, increasing laminar wind speed, Knowles microphone.

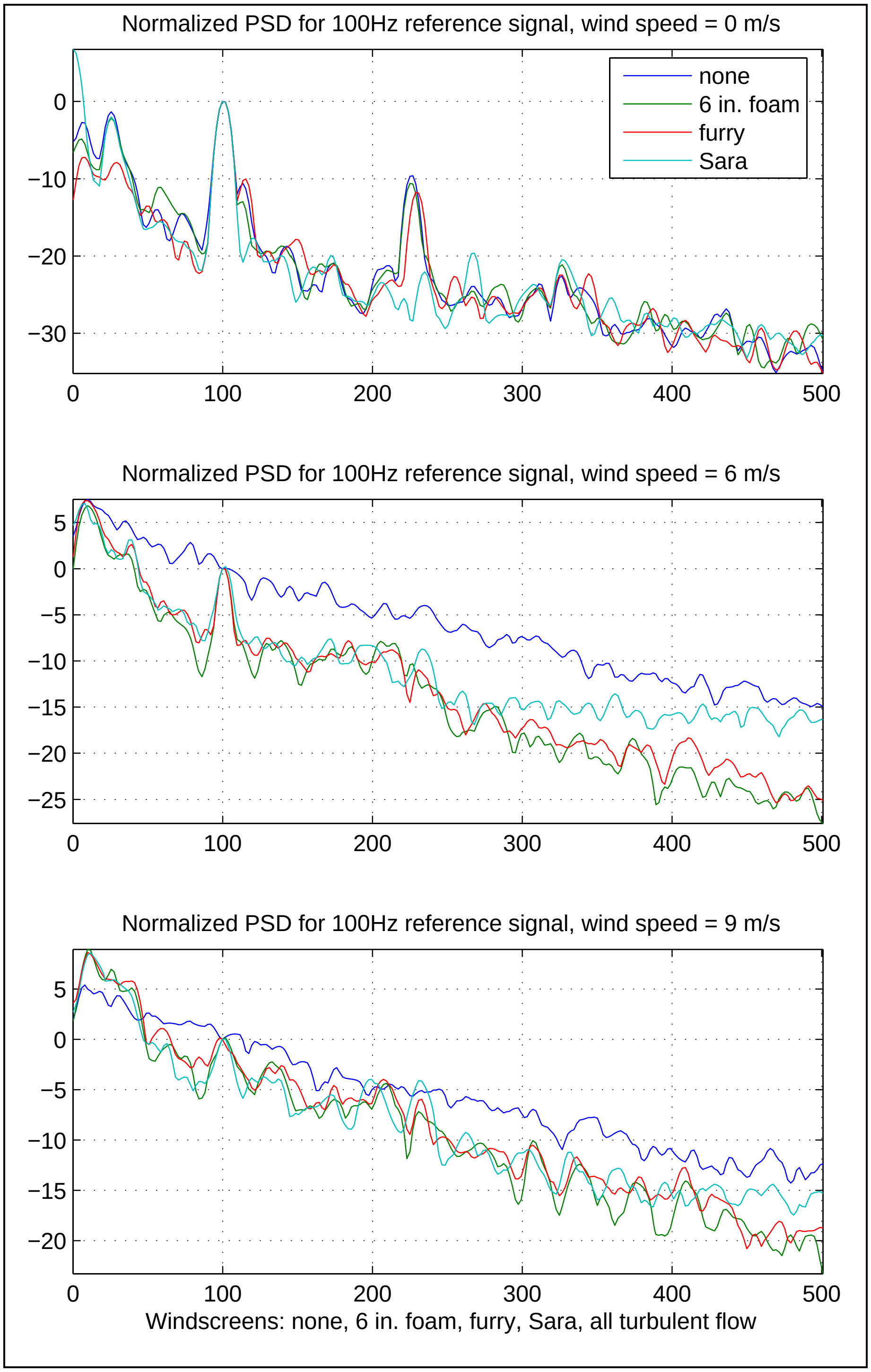

Figure 10. PSD normalized at 100 Hz, increasing turbulent wind speed, Knowles microphone.

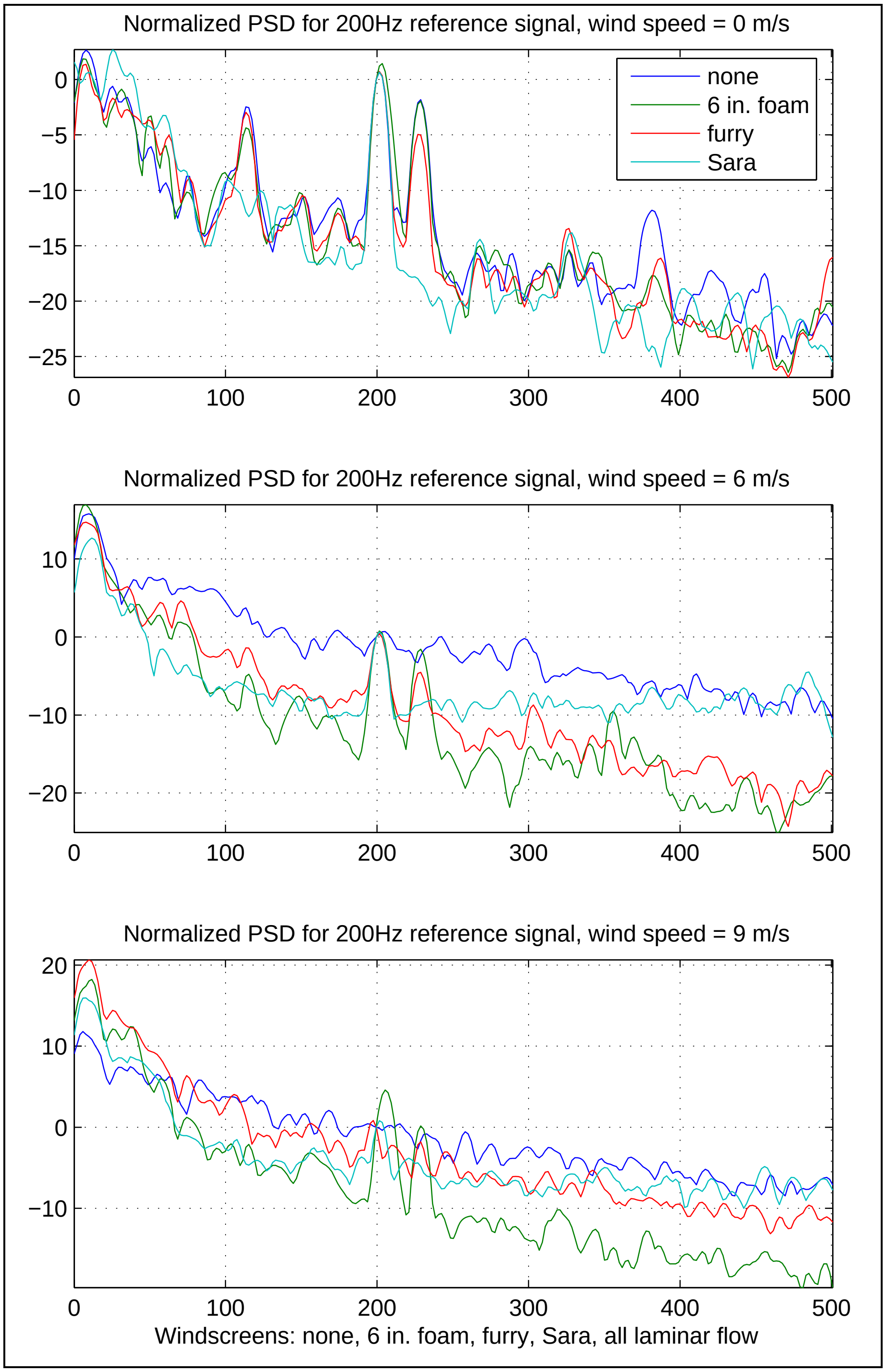

Figure 11. PSD normalized at 200 Hz, increasing laminar wind speed, Knowles microphone.

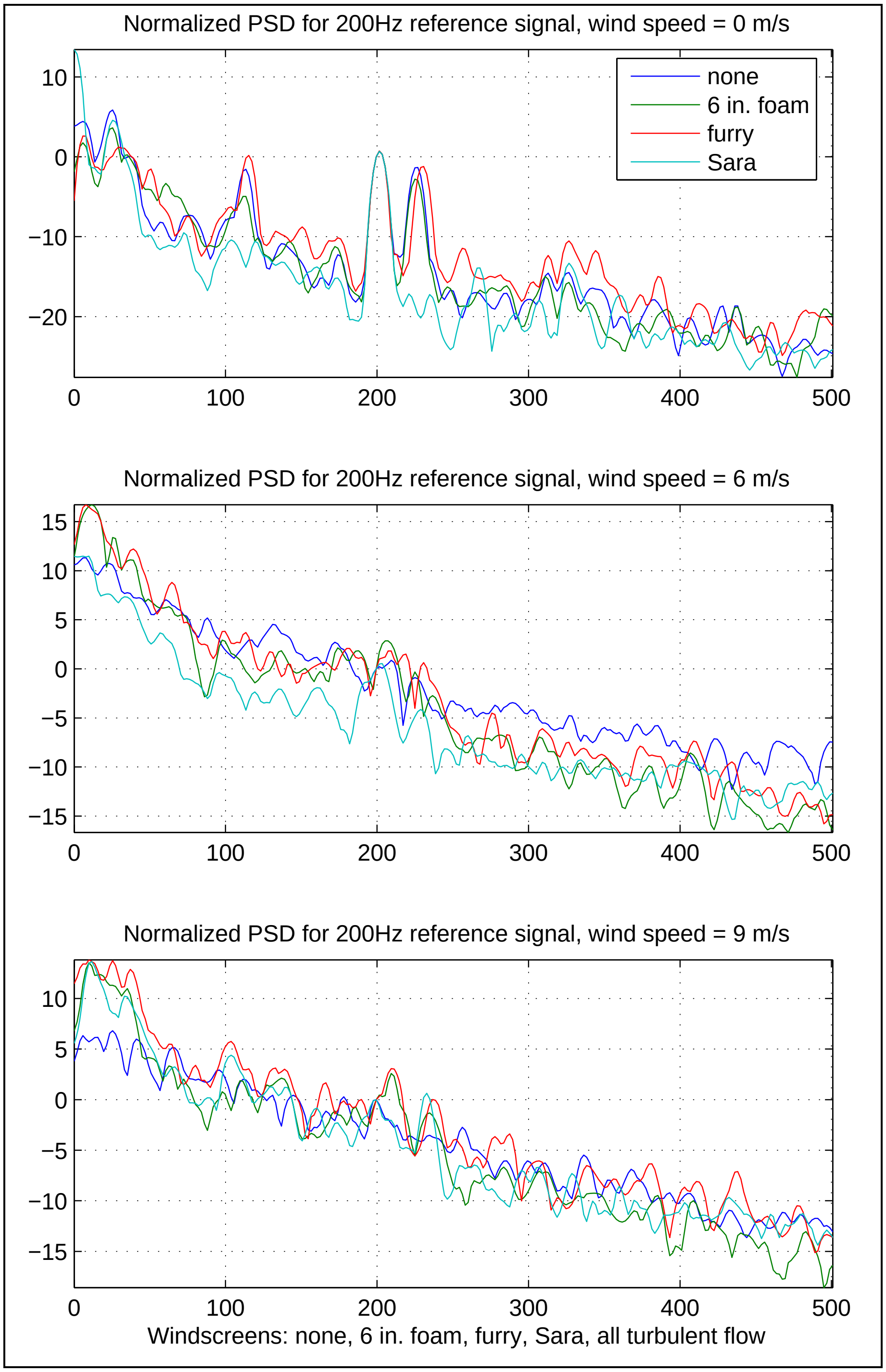

Figure 12. PSD normalized at 200 Hz, increasing turbulent wind speed, Knowles microphone.

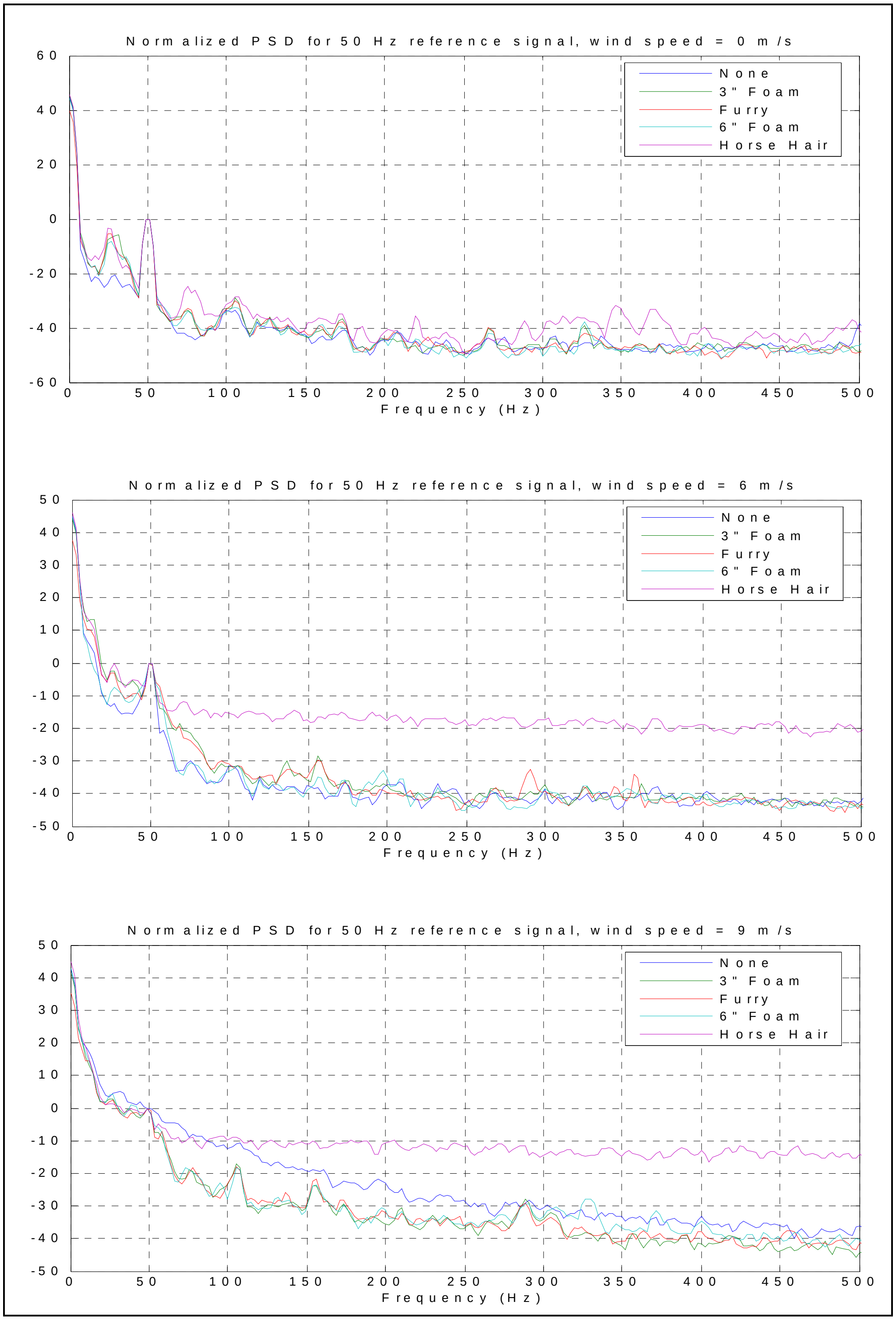

Figure 13. PSD normalized at 50 Hz, increasing laminar wind speed, B&K microphone.

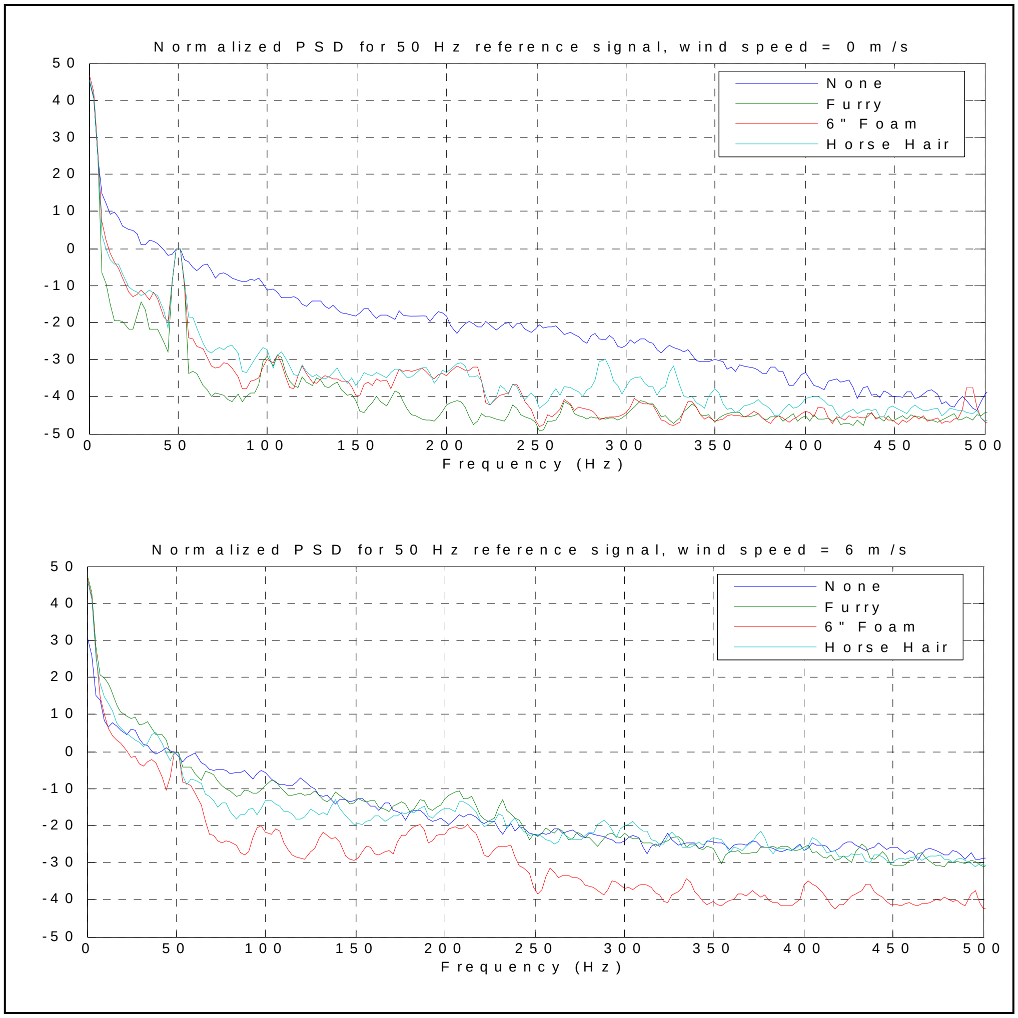

Figure 14. PSD normalized at 50 Hz, increasing turbulent wind speed, B&K microphone.

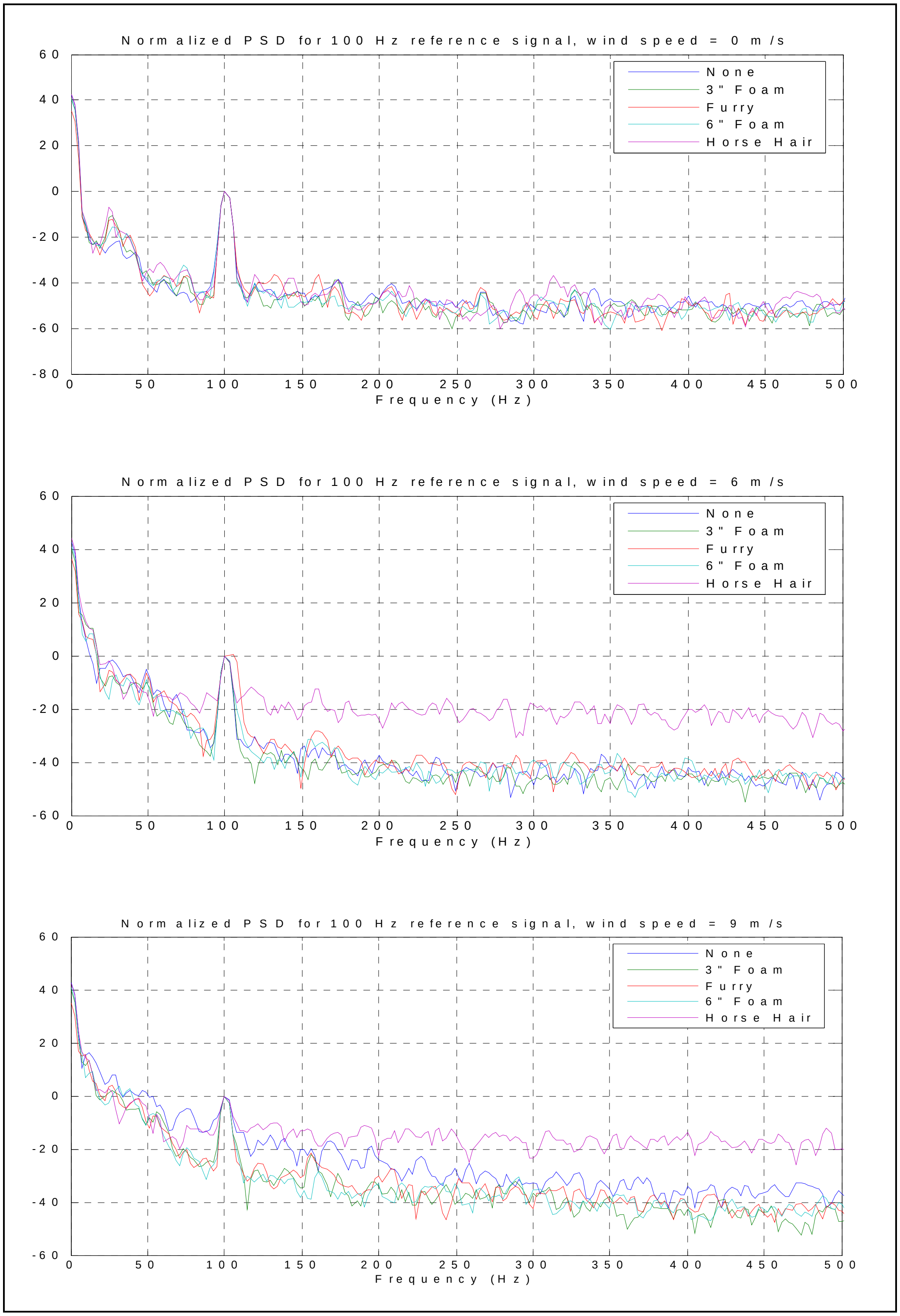

Figure 15. PSD normalized at 100 Hz, increasing laminar wind speed, B&K microphone.

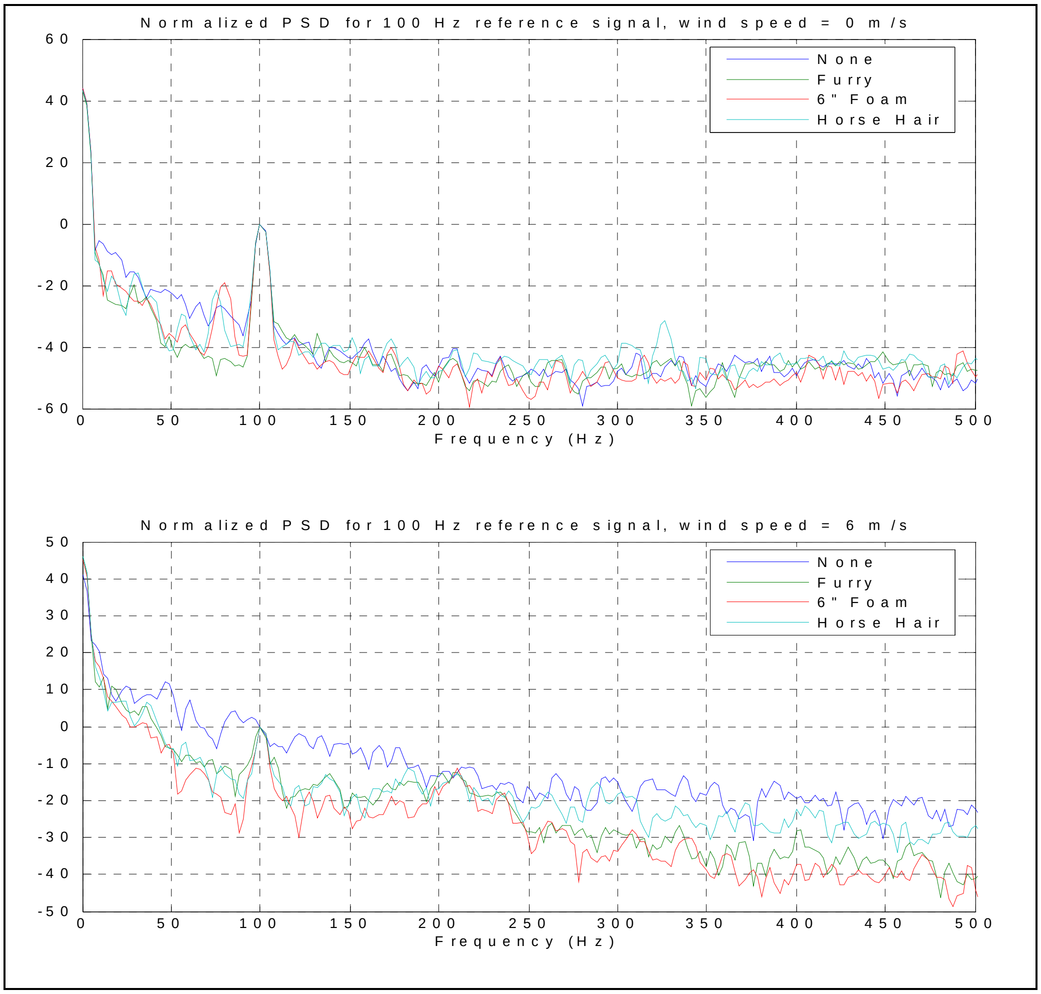

Figure 16. PSD normalized at 100 Hz, increasing turbulent wind speed, B&K microphone.

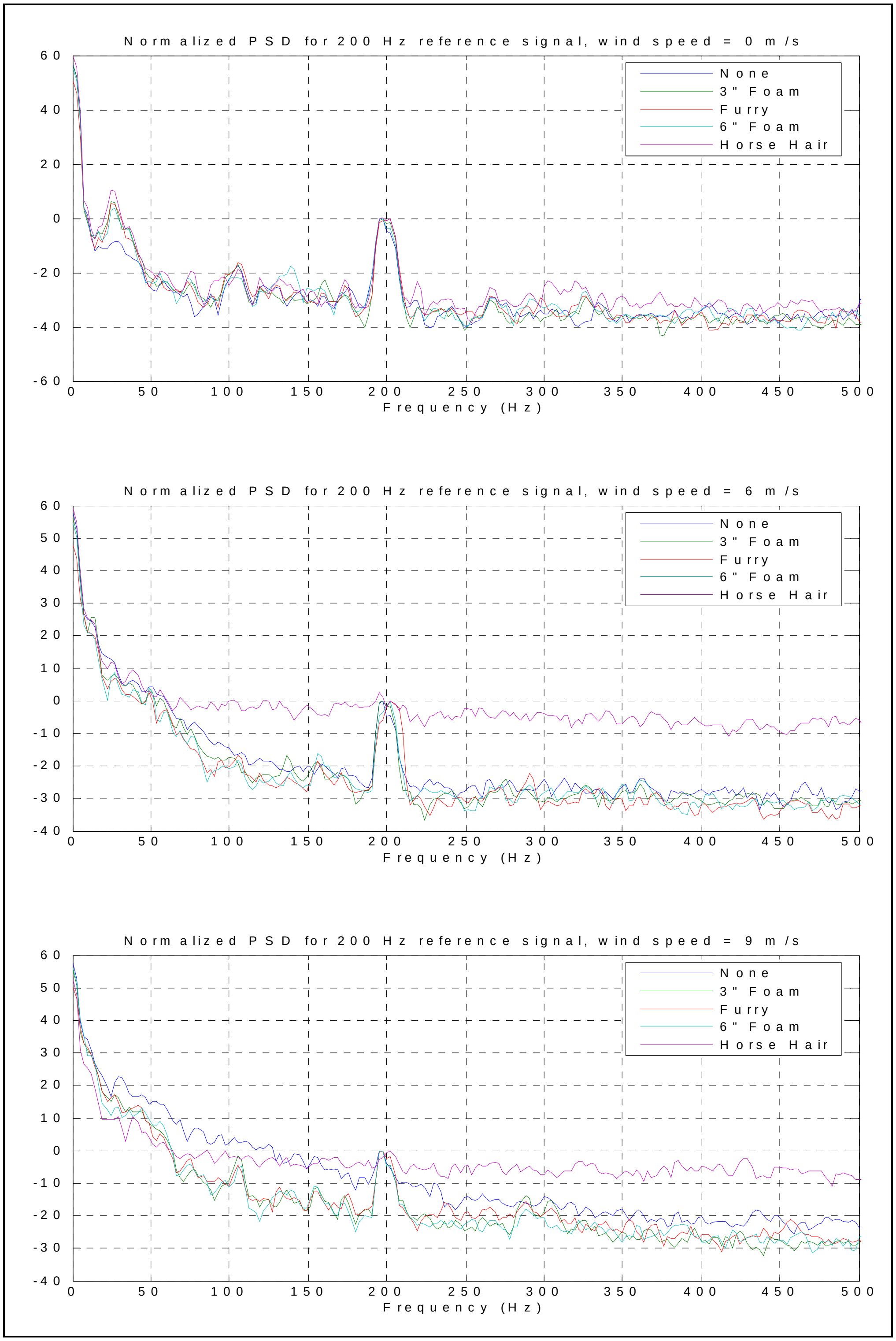

Figure 17. PSD normalized at 200 Hz, increasing laminar wind speed, B&K microphone.

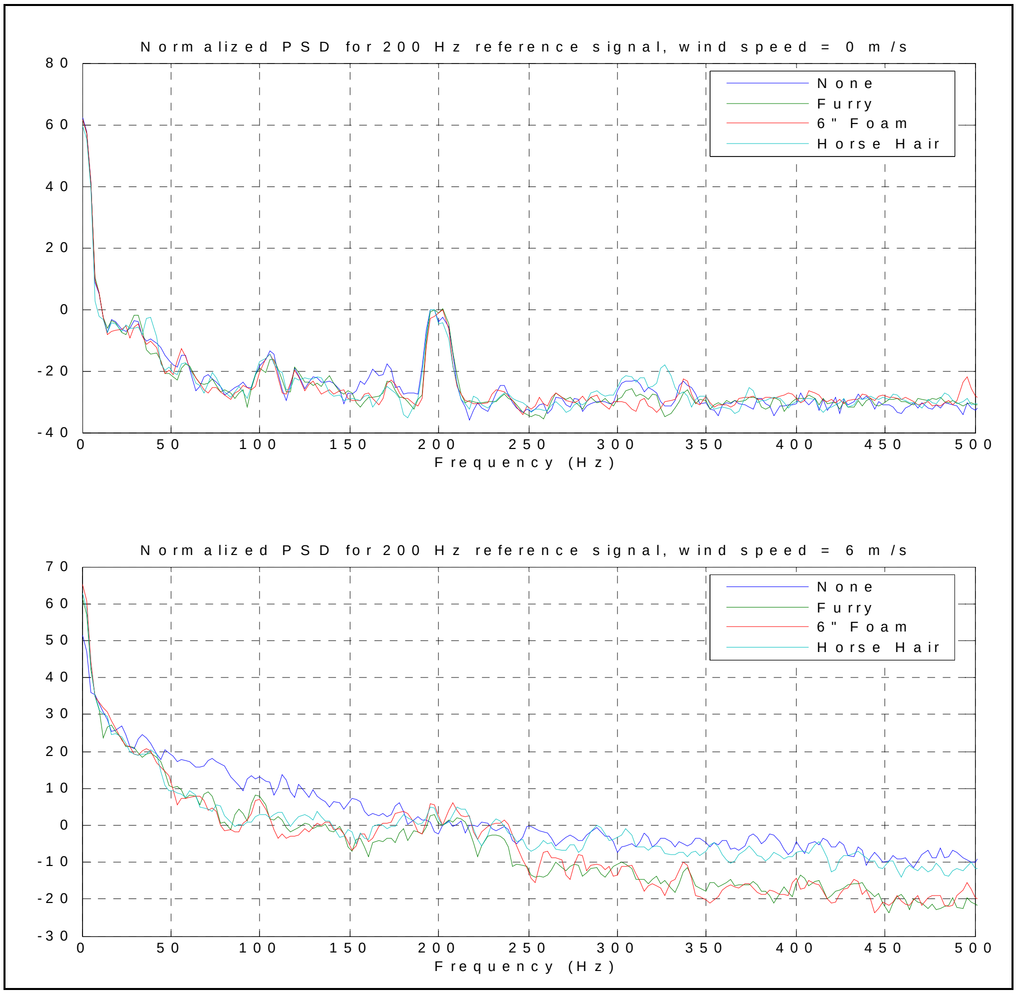

Figure 18. PSD normalized at 200 Hz, increasing turbulent wind speed, B&K microphone.

In general, the reference signal is unobservable for wind noise beyond 9 m/s. B&K results for 9 m/s turbulent wind flow were excluded from this report because the noise level greatly exceeded that of the reference tone. Tones are observable at approximately 225 Hz, possibly due to the frequency of the tunnel fan.

Discussion

We have developed two figures of merit to quantify the relative quality of each windscreen. The first measures the power of the signal as normalized in figures 7 through 12. Intuitively, since the reference tone (plus noise at that frequency) has a power of 0 dB, the remaining power in the other frequency bin tells how much the wind noise has been suppressed relative to the tone. The second figure measures the ratio of the signal power relative to that with 0 wind speed, averaged

over all frequencies. The reasoning here is that a good windscreen should keep the increase in power as small as possible as wind speed increases, at all frequencies.

The following two tables contain the results for the first measure, the power of the normalized signal for both the Aerostat box and the B&K microphone, respectively, as the windscreens are varied. The 3" foam windscreen was destroyed in the wind tunnel during testing, and no qualitative results were produced for turbulent wind flow of 9 m/s. These fields have an x in them indicating no results are available. All numbers are in unit of power.

Table 1. Power of normalized power spectrum density for the Aerostat and B&K microphone, respectively.

Reference tone 50Hz	Laminar flow (m/s)			Turbulent flow (m/s)		
	0	6	9	0	6	9
No windscreen	0.0162	**0.2540**	0.5753	0.1165	**0.2710**	**0.3306**
6in foam ball	**0.0152**	0.3687	1.3506	0.0239	0.4617	1.0308
Fur ball	0.0165	0.3985	1.6643	**0.0160**	0.4973	0.7360
Sara	0.0257	0.4184	**1.2012**	0.2472	0.5793	1.0100

Reference tone 100Hz	Laminar flow (m/s)			Turbulent flow (m/s)		
	0	6	9	0	6	9
No windscreen	**0.0154**	0.4254	0.4780	0.0279	1.6640	**0.9327**
6in foam ball	0.0171	0.4619	**1.5147**	0.0223	**0.6165**	1.8882
Fur ball	0.0169	**0.3228**	4.4402	**0.0157**	0.9047	1.9686
Sara	0.0223	0.4239	2.2621	0.2207	0.7479	1.7699

Reference tone 200Hz	Laminar flow (m/s)			Turbulent flow (m/s)		
	0	6	9	0	6	9
No windscreen	0.1199	39.5543	**8.2815**	0.4442	10.7885	**1.9082**
6in foam ball	0.1042	48.7188	99.8733	0.1661	65.4344	17.3944
Fur ball	**0.0775**	23.9364	307.0050	**0.1608**	70.8341	32.6685
Sara	0.1502	**7.7160**	40.9737	4.3240	**7.3256**	14.0140

Reference Tone 50 Hz	Laminar Flow (m/s)			Turbulent Flow (m/s)		
	0	6	9	0	6	9
No Windscreen	41638	42455	24318	**43286**	**1621**	xxxx
3” Foam	47653	35362	18978	xxxxx	xxxxx	Xxxxx
6” Foam	36532	39243	26693	63328	58049	xxxx
Furry	**13582**	**7755**	**4894**	45015	71489	xxxx
Horse Hair	50409	54567	41780	48762	50083	xxxx

Reference Tone 100 Hz	Laminar Flow (m/s)			Turbulent Flow (m/s)		
	0	6	9	0	6	9
No Windscreen	22420	25579	25260	34522	**17750**	xxxx
3” Foam	15328	13269	13083	xxxxx	xxxxx	xxxx
6” Foam	14557	17469	16596	34958	43662	xxxx
Furry	**4486**	**5872**	**4383**	**26738**	54921	xxxx
Horse Hair	24076	34338	23605	30568	55791	xxxx

Reference Tone 200 Hz	Laminar Flow (m/s)			Turbulent Flow (m/s)		
	0	6	9	0	6	9
No Windscreen	633930	814640	766210	2248300	**204230**	xxxx
3” Foam	603400	542480	470000	xxxx	xxxxx	xxxx
6” Foam	454020	403100	578360	2015900	4496200	xxxx
Furry	**154480**	**88564**	**165200**	1911500	1911900	xxxx
Horse Hair	1355000	1181300	241460	**1245900**	2642700	xxxx

One might notice, even in the absence of a windscreen, the Knowles microphone seems to do pretty well. This is misleading because, in the absence of wind, there is a peak around 10 Hz in the frequency response (25 Hz for the Sara windscreen). When the wind blows and there is no windscreen, those peaks are buried in the noise and are not accounted for in this performance measure. The other windscreens actually did a better job at suppressing the wind noise, so the peaks are still apparent, and contribute to a bigger (and less desirable) total power.

The Sara windscreen seems to perform well with a 6 m/s wind speed and a 200 Hz reference tone. But the numbers seem way out of range when compared to the others. The second figure of merit discussed later will have to confirm this.

The data taken with the B&K microphone does not show the peaks at 10 and 25 Hz. In fact, for the B&K, the noise floor clearly follows a 1/f shape. We believe the peaks observed with the Knowles microphone are due to its characteristic roll-off at low frequency, filtering out the 1/f spectrum.

The furry windscreen produces the best result for laminar wind flow. A closer look, however, reveals that it is cutting off very low frequencies, which make disproportionately a big contribution in the 1/f shape (this is more obvious on a linear scale). This roll-off is not apparent in turbulent flow though. It could be because turbulent flow does not persistently press the fur down, and thus decreasing its acoustic impedance. It also could be that the turbulences shake the fur around, creating additional low frequency noise.

In any case, this measure for performance is sensitive to the normalization factor, which is computed from the data at just one frequency, and therefore subject to measurement noise and estimation method. Furthermore, it is skewed by the 1/f shape of the noise power spectrum density, in which lower frequency components contribute more. This is the reason why we develop the second figure to measure performance of the windscreens.

Table 2 shows the results for the second measure of performance, on the log base 10 scale.

Table 2. Average power ratio increase.

	Windscreen	Wind speed increase (m/s)	Reference tone (Hz)		
			50	100	200
Laminar flow	No windscreen	0 to 6	26.7034	27.9345	27.7828
		0 to 9	38.1316	27.9345	39.315
	6in foam ball	0 to 6	15.6251	15.5486	16.6762
		0 to 9	21.7195	15.5486	20.7634
	Furry	0 to 6	12.7419	15.0092	17.0949
		0 to 9	18.4549	15.0092	22.5587
	Sara	0 to 6	28.7266	28.2118	24.0547
		0 to 9	27.2516	28.2118	24.1352
Turbulent flow	No windscreen	0 to 6	46.6988	52.7088	46.412
		0 to 9	52.9758	52.7088	55.6514
	6in foam ball	0 to 6	20.7466	22.7207	22.6645
		0 to 9	31.5563	22.7207	31.7719
	Furry	0 to 6	23.6991	24.2702	24.7766
		0 to 9	33.3873	24.2702	34.2041
	Sara	0 to 6	25.5349	27.3056	25.578
		0 to 9	34.3319	27.3056	35.0705

	Windscreen	Wind Speed Increase (m/s)	Reference Tone (Hz)		
			50	100	200
Laminar Flow	None	0 to 6	7.6825	14.5182	14.3742
		0 to 9	24.4743	25.4477	25.9332
	3” Foam	0 to 6	10.8484	12.6172	12.2785
		0 to 9	14.6122	16.6620	16.8732
	6” Foam	0 to 6	6.1880	11.2458	10.5471
		0 to 9	15.2652	16.0292	17.1639
	Furry	0 to 6	9.7312	13.4756	12.0534
		0 to 9	15.6836	17.2128	17.3697
	Horse Hair	0 to 6	20.6353	24.8606	24.0764
		0 to 9	28.5863	32.1873	31.2105
Turbulent Flow	None	0 to 6	24.5807	32.9477	39.3432
		0 to 9	xxx	xxx	xxx
	3” Foam	0 to 6	xxx	xxx	xxx
		0 to 9	xxx	xxx	xxx
	6” Foam	0 to 6	8.5453	22.2130	19.4263
		0 to 9	xxx	xxx	xxx
	Furry	0 to 6	21.6488	22.5974	21.9895
		0 to 9	XXX	XXX	XXX
	Horse Hair	0 to 6	14.8393	20.8791	20.8535
		0 to 9	XXX	XXX	XXX

Smaller numbers are better since they indicate that the windscreen effectively suppresses the wind noise. The catch here is that, if we completely isolate the microphone, we get the best possible windscreen (negative numbers). However, there is a risk that the sound of interest will also be suppressed. Ideally, the reference tone should increase in power. However, due to spectral leakage, accounting for it would require more complications.

Even though this performance measure is not perfect, it still gives numbers that agree with the figures 7 through 12. Namely, the 6 in. foam ball generally performs best, followed by the furry windscreen, then by the Sara windscreen. Measurements with the B&K microphone again confirm this behavior.

The reason the Sara appears to do worse than the furry windscreen is because it does not suppress high frequency wind noise very well, although it does a decent job at low frequency. Adding up all frequencies shows that effect.

It has been observed during the setup that the Sara windscreen was not parallel to the wind flow. That might have created local turbulences on the windscreen itself, which would have increased the wind noise. However, we have been informed that the skew of 12 degrees (as it was) is within operating tolerance of the windscreen (±15 degrees).

Conclusion

Consistent with theory, we found that turbulent flow noise is harder to suppress than laminar flow noise for all windscreens. Most windscreens perform in the same range with the 6 in. foam ball edging out the others. One might argue that the Sara microphone was not parallel to the laminar flow and could do better in that situation. In addition, our performance measures may still have room for improvement.

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